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CALCULATED EFFECT OF SOME AIRPLANE HANDLING TECHNIQUES ON THE GROUND-RUN DISTANCE IN LANDING ON SLIPPERY RUNWAYS

By John A. Zalovcik

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SUMMARY

Some calculations were made on the basis of simplifying assumptions to determine the effect on the ground-run distance of maintaining a nose-high attitude instead of a three-point attitude in landings of several types of jet airplanes on slippery runways. The airplanes considered were a swept-wing transport and unswept-, swept-, and delta-wing fighters. The effect of such factors as speed, braking effectiveness, and residual thrust on the difference in ground-run distance with the two handling techniques is briefly considered. Some computations were also made to indicate the effect of instantaneous flap retraction on the ground-run distance.

INTRODUCTION

In the problem of arresting airplanes landing on slippery runways, some question has been raised as to whether a shorter ground run may be effected by nosing an airplane down to the three-point attitude immediately after touchdown and applying the brakes than by maintaining a nose-high attitude angle for some distance down the runway, subsequently lowering the nose wheel to the runway, and then applying the brakes. Pilots of some fighter airplanes landing on runways during, or immediately after, a heavy rain have been reported to make use of the nose-high-attitude technique. This technique is also reported to have been used by some pilots of transports on dry runways.

The chief purpose of this analysis is to indicate by simplified calculation the possible differences in ground-run distances for several types of jet airplanes obtained by using the two previously described techniques in landing on slippery runways. The effect of such factors as speed, braking effectiveness, and idling thrust on the difference in ground-run distance with the two handling techniques is also briefly considered.

Because the question is often raised as to the effectiveness of retracting flaps during a ground run, some results are presented for the effect of instantaneous flap retraction at ground contact on the ground-run distance.

Ground-run distances are presented for runway surface conditions having maximum available tire-to-ground friction coefficients below 0.3. Friction coefficients in this range would include, for example, coefficients typical of landings on wet runways at high speeds, on snow-covered runways, and on icy surfaces.

SYMBOLS

C_D	airplane drag coefficient
C_L	airplane lift coefficient
$\Delta C_{D,f}$	increment in drag coefficient due to flap
$\Delta C_{L,f}$	increment in lift coefficient due to flap
g	acceleration due to gravity, 32.2 ft/sec^2
i_w	wing incidence with respect to fuselage reference line, deg
L	airplane lift, lb
q	dynamic pressure, $\frac{\rho V^2}{2}$, lb/sq ft
S	airplane wing area, sq ft
s	ground-run distance, ft
T	residual or idling thrust, lb
t	time, sec
V	airplane speed, ft/sec
W	airplane weight, lb
α	angle of attack of fuselage reference line, deg

α_m angle of attack maintained after touchdown in landing, deg

ρ sea-level density, slugs/cu ft

μ friction coefficient

μ_a maximum available tire-to-ground friction coefficient

μ_b airplane braking coefficient

μ_r rolling-friction coefficient, 0.02

Subscripts:

g at three-point attitude

max maximum

n at time when airplane is nosed down from a high-attitude angle during ground run to a three-point attitude

s at stall; also at time when $W = SqC_{L,max}$

t at moment of touchdown

METHOD OF ANALYSIS

Airplanes

For the purpose of evaluating the effect of a nose-high attitude angle on the ground-run distance necessary in airplane landings, several jet airplanes considered typical of modern aircraft have been selected for study. The airplanes chosen include a sweptback-wing jet transport, three sweptback-wing fighters (identified as fighters A, B, and C), an unswept-wing fighter, and a delta-wing fighter. Some of the physical characteristics of these airplanes are given in table I. The aerodynamic characteristics necessary for the calculations were obtained from available wind-tunnel and flight data, or were estimated when such data were not available, and are shown in figure 1. Corrections for ground effect were estimated by method of reference 1.

The effect of flap retraction on landing ground-run distance was calculated for all airplanes except the tailless delta-wing fighter. The increments in lift and drag coefficients contributed by the flaps are given in table II.

Effect of Airplane Attitude

Landing distance for $V_t = 1.05V_s$.- The type of variation of angle of attack with speed assumed in the computation of the landing ground-run distance is illustrated in figure 2 for a touchdown speed V_t of 5 percent above the stalling speed V_s, which corresponds to a lift coefficient of $0.91C_{L,max}$. The curve labeled "a" corresponds to a landing in which the pilot maintains the angle of attack corresponding to 5 percent above stalling speed until a speed V_n is reached. The angle of attack is then assumed to be decreased instantly at speed V_n to the three-point attitude and kept at this attitude for the rest of the ground run. The curve labeled "b" corresponds to a landing in which the pilot noses the airplane down to the three-point attitude at the instant of contact. In the handling technique indicated by curve a, the brakes are applied only after the airplane is nosed down to the three-point attitude. For the technique indicated by curve b the brakes are assumed to be applied immediately on touchdown. During braking, the entire vertical load (W - L) is assumed to be taken on the main wheels. For the handling technique indicated by curve b, this assumption will amount to the use of just enough elevator to keep the load off the nose wheel. At speeds below V_n the airplane will be at the three-point attitude for both handling techniques and, consequently, that part of the ground-run distance between speeds V_n and 0 is the same for both techniques. For the unswept- and swept-wing airplanes considered herein, the flaps are assumed to remain down throughout the ground run.

The landing ground-run distance in the absence of wind is computed on the basis of the equation

$$\frac{W}{g}\frac{dV}{dt} = -C_D S q - \mu(W - L) + T$$

or, in an alternate form,

$$\frac{1}{g\rho}\frac{dq}{ds} = -\frac{C_D q}{C_{L,t} q_t} - \mu\left(1 - \frac{C_L q}{C_{L,t} q_t}\right) + \frac{T}{W} \qquad (1)$$

where, at touchdown, it is assumed that

$$W = C_{L,t} q_t S$$

In the integration of equation (1), the friction coefficient μ is taken as a constant rolling-friction coefficient μ_r during the nose-high-attitude part of the ground run and as a constant braking coefficient μ_b during the three-point-attitude part of the run. Since the value of μ_r is small (taken here as 0.02) (refs. 2 and 3), its variation with speed would have a negligible effect on the landing ground-run distance. The braking coefficient μ_b depends on the pilot's technique in applying the brakes, on the range of tire-skidding velocities over which antiskid devices operate (if the airplane is so equipped), on the brake torque limitation (which is a function of speed and brake temperature), and on the runway surface condition (which determines the maximum available tire-to-ground friction coefficient μ_a). Information on the variation of μ_a with speed is very meager. On slippery surfaces, such as those represented by values of μ_a between 0.05 and 0.3, μ_a probably does not vary much with speed. In view of the varying nature of the several factors that affect μ_b, the value of μ_b cannot be expressed explicitly as a function of speed and, hence, is assumed to be constant for a given runway condition in the integration of equation (1). On the basis of these assumptions, the integration of equation (1) yields the ground distance s, as follows:

$$s = \frac{q_t}{g\rho}\left\{\frac{1}{\mu_r - \frac{C_{D,t}}{C_{L,t}}}\log_e \frac{\mu_r - \left(\mu_r - \frac{C_{D,t}}{C_{L,t}}\right)\frac{q_n}{q_t} - \frac{T}{W}}{\frac{C_{D,t}}{C_{L,t}} - \frac{T}{W}} + \frac{1}{\mu_b \frac{C_{L,g}}{C_{L,t}} - \frac{C_{D,g}}{C_{L,t}}}\log_e \frac{\mu_b - \frac{T}{W}}{\mu_b - \frac{T}{W} - \left(\mu_b \frac{C_{L,g}}{C_{L,t}} - \frac{C_{D,g}}{C_{L,t}}\right)\frac{q_n}{q_t}}\right\} \tag{2}$$

The first term on the right-hand side of equation (2) represents the distance during that part of the ground run with the nose-high attitude and the second term, the distance during that part with the airplane at the three-point attitude. Solution of equation (2) for various values of $\frac{q_n}{q_t} < 1.0$ yields the ground-run distance for curve a of figure 2;

whereas the solution with $\frac{q_n}{q_t} = 1.0$ gives the distance for curve b since the first term on the right-hand side of equation (2) becomes zero.

Equation (2) is valid up to the lowest value of μ_a that permits development of maximum braking torque for continuous operation. For the present-day transports the maximum braking torque for continuous operation appears to be in the range that would provide a decelerating force due to braking of 0.2W to 0.3W. If the higher of these two values is assumed, as it is herein, the lowest value of μ_a at which maximum braking torque for continuous operation is developed will be, for example, 0.3 for $\mu_b = \mu_a$, 0.4 for $\mu_b = 0.75\mu_a$, and 0.6 for $\mu_b = 0.50\mu_a$. The calculations are therefore made for values of μ_a up to that at which the maximum braking torque will be developed. If stopping distances at higher values of μ_a are desired, the friction term $\mu(W - L)$ in equation (1) will have to be replaced by 0.3W at the time during the run when maximum braking torque is developed.

The ground-run distance for attitude angles α_m other than that corresponding to a speed 5 percent above stalling speed is calculated for the swept-wing fighters B and C and the delta-wing fighter touching down at 5 percent above stalling speed. The assumed variation of angle of attack with speed for these airplanes is illustrated in figures 3 to 5.

Landing distance for $V_t = 1.30V_s$.- For comparison with the distance at a touchdown speed of 5 percent above stalling speed, the ground-run distance for the delta-wing fighter is calculated for a touchdown speed of 30 percent above stalling speed with several attitude angles α_m. The assumed variation of angle of attack with speed during the ground run for various attitude angles is illustrated in figure 6. For attitude angles greater than the angle of attack corresponding to a speed 30 percent above stalling speed, the pilot is assumed to increase the angle of attack as the speed decreases, in such a way that the lift of the airplane is equal to the weight until the desired ground-attitude angle is attained. The ground run is then continued at this angle down to speed V_n at which the angle of attack is assumed to decrease instantly to the three-point attitude and the brakes are applied. The ground-run distance is given by the equation

$$s = -\frac{1}{g\rho}\int_{q_t}^{q_s}\frac{dq}{\frac{T}{W} - \frac{C_D}{C_L}} +$$

$$\frac{q_s}{g\rho}\left[\frac{1}{\mu_r - \frac{C_{D,s}}{C_{L,s}}}\log_e \frac{\mu_r - \left(\mu_r - \frac{C_{D,s}}{C_{L,s}}\right)\frac{q_n}{q_s} - \frac{T}{W}}{\frac{C_{D,s}}{C_{L,s}} - \frac{T}{W}} + \right.$$

$$\left. \frac{1}{\mu_b \frac{C_{L,g}}{C_{L,s}} - \frac{C_{D,g}}{C_{L,s}}}\log_e \frac{\mu_b - \frac{T}{W}}{\mu_b - \frac{T}{W} - \left(\mu_b \frac{C_{L,g}}{C_{L,s}} - \frac{C_{D,g}}{C_{L,s}}\right)\frac{q_n}{q_s}}\right] \qquad (3)$$

The first term on the right-hand side of equation (3) is the distance during the part of the run when $L = W$. The second term is the distance for that part of the run with the constant nose-high angle of attack. The last term is the distance for the braking part of the run with the airplane at the three-point attitude. For attitude angles less than that corresponding to a speed of 30 percent above stalling speed, the angle of attack is assumed to decrease instantly at contact to the desired attitude angle. The ground run is then continued at this attitude down to speed V_n at which the angle of attack is assumed to decrease instantly to the three-point attitude and the brakes are applied. The ground-run distance is given by equation (2) for this case.

Effect of Flap Retraction

The ground-run distance with flaps retracted is calculated for all airplanes except the tailless delta-wing airplane by using equation (2) and assuming that the airplane is nosed down to a three-point attitude $\left(\frac{q_n}{q_t} = 1.0\right)$ with the flaps retracted at the instant of ground contact. The entire vertical load is assumed to be carried on the main wheels.

RESULTS

Effect of Airplane Attitude

Landing distance at $V_t = 1.05V_s$.- The landing ground-run distance for several types of jet airplanes touching down at 5 percent above stalling speed is shown in figure 7 for various conditions of the runway, as indicated by the maximum available tire-to-ground friction coefficient μ_a, and for various values of $\left(\frac{V_n}{V_t}\right)^2 = \frac{q_n}{q_t}$. The braking coefficient μ_b is assumed equal to the maximum available tire-to-ground friction coefficient μ_a. The curves labeled $\left(\frac{V_n}{V_t}\right)^2 = 1.0$ represent the ground-run distances for the handling technique (indicated by curve b in fig. 2) where the angle of attack is decreased immediately to the three-point attitude at touchdown. Curves labeled $\left(\frac{V_n}{V_t}\right)^2 = 0.8$, 0.6, and 0.4 represent ground-run distances for the handling technique (indicated by curve a in fig. 2) where the attitude angle corresponding to that for 5 percent above stalling speed was maintained until the dynamic pressure had decreased to values of 80, 60, and 40 percent of the dynamic pressure at touchdown, respectively.

According to figures 7(a), 7(b), and 7(e) there is no advantage in maintaining a nose-high-attitude angle after touchdown for the unswept-wing fighter, the swept-wing fighter A, or the swept-wing transport. In fact, for these three airplanes the ground-run distance increases considerably for tire-to-ground friction coefficients greater than 0.05, which represents a very slippery surface. For the swept-wing fighters B and C (figs. 7(c) and 7(d)), some small reduction in ground-run distance can be obtained for values of μ_a less than about 0.10. At values of μ_a greater than 0.10, the increase in ground-run distance is appreciable.

The effect on the ground-run distance of limiting the attitude angle in landing is illustrated in figures 8 to 10. If the maximum attitude angle were limited, for example, by tail-pipe clearance, to 10° instead of 16° for swept-wing fighter B, and to 5° instead of 9° for swept-wing fighter C, the nose-high-attitude technique would result in an increase in ground-run distance even at values of μ_a down to approximately 0.05. For the delta-wing fighter operating at an attitude angle corresponding to 5 percent above stalling speed (about 20°), the reduction in ground-run distance (fig. 10(a)) is obtained at values of μ_a below approximately 0.2 with rather large reductions obtainable on very slippery

surfaces $\left(\mu_a = 0.05\right)$. For an attitude angle of 15°, only small reductions in distance are obtained and only at values of μ_a less than approximately 0.08 (fig. 10). For an attitude angle limited to a maximum of 10°, no reduction is obtained with the nose-high-attitude technique down to a value of μ_a of 0.05.

<u>Landing distance at $V_t = 1.30V_s$</u>.- The ground-run distance for the delta-wing fighter landing at a speed of 30 percent above stalling speed is shown in figure 11 for several attitude angles. The curves labeled $\left(\frac{V_n}{V_t}\right)^2 = 0.26$, 0.39, and 0.52 correspond to curves of figure 8 labeled $\left(\frac{V_n}{V_t}\right)^2 = 0.4$, 0.6, and 0.8, respectively, inasmuch as the corresponding curves have the same value of V_n. A comparison of figures 10 and 11 indicates that the value of μ_a below which a reduction in ground-run distance is obtained with the nose-high-attitude technique is about the same for the two touchdown speeds. The reduction or increase in distance both in percent and in absolute magnitude, however, is appreciably greater for the higher touchdown speed.

<u>Landing distance with reduced brake effectiveness</u>.- The ground-run distance for the delta-wing fighter with reduced brake effectiveness is shown in figure 12 for a touchdown speed of 5 percent above stalling speed. The angle of attack during the nose-high attitude of the ground run was taken as 20°. Curves are shown for braking coefficients μ_b of 100, 75, and 50 percent of the maximum available tire-to-ground friction coefficient μ_a. A braking coefficient considerably less than the maximum available tire-to-ground friction coefficient may be obtained as a result of cycling of the antiskid device over too great a range of skidding velocities, of inefficient braking by the pilot, or of insufficient brake torque. As an example of the efficiency of one installation of antiskid devices, some recent NACA tests of an airplane equipped with one type of antiskid device indicated an average braking coefficient μ_b of about $0.7\mu_a$ while the device cycled over a range of tire-skidding velocities from 0 to about 70 percent of the unbraked-wheel rolling velocity. The results in figure 12 show that, as the braking coefficient μ_b is reduced, the nose-high-attitude technique gives greater reductions in ground-run distance on the very slippery surfaces. The value of μ_a below which the reductions are obtained is increased by the factor μ_a/μ_b. For example, for the delta-wing fighter with $\alpha_m = 20^\circ$, reductions are obtained at μ_a below about 0.2 for $\mu_b = \mu_a$ and at μ_a below about 0.4 for $\mu_b = 0.5\mu_a$.

Landing distance with residual thrust.- The effect of the residual (idling) thrust T on the ground run of the delta-wing fighter is indicated in figure 13, which shows a comparison of the ground-run distance for $T/W = 0$ and 0.025. For a ratio of maximum thrust to weight of 0.5, the value of $T/W = 0.025$ corresponds to a residual thrust of 5 percent of maximum thrust. With this residual thrust the ground-run distance on very slippery surfaces $\left(\mu_a = 0.05\right)$ is, of course, excessive for the condition when the airplane is nosed down to the three-point attitude immediately and brakes are applied $\left(V_n = V_t\right)$. Although the reductions in distance obtained by maintaining a nose-high attitude are rather large for this surface condition, the ground-run distance is still so great as perhaps to require other arresting means. (It should be noted that an antiskid device which would give a braking coefficient equal to the maximum available tire-to-ground coefficient is assumed to be operating during braking, a condition that does not appear to be realized in practice.) The reduction in ground-run distance obtained by maintaining a nose-high attitude is obtained at values of μ_a less than about 0.2 for a residual thrust of both 0 and 0.025W, but the reductions are greater with a residual thrust of 0.025W. The effect of the residual thrust at the low values of μ_a is approximately equivalent to a reduction in the value of μ_a by the value of T/W.

Energy input to brakes.- The use of the nose-high-attitude technique results in a reduction in the energy input to the brakes and hence in a reduction of brake and tire wear. The reduction in the energy absorbed by the brakes, expressed as a fraction of the energy absorbed by the brakes when $\frac{V_n}{V_t} = 1.0$, is given approximately by the expression $\left(1 - \left(\frac{V_n}{V_t}\right)^2\right)$. For the conditions in which the nose-high attitude results in a decrease in the ground-run distance, the advantages of this technique are twofold. For conditions in which the nose-high attitude results in an increase in ground-run distance, the reduction in energy input to the brakes will depend on the increase in ground-run distance that can be tolerated. When the airplane has insufficient brake capacity to absorb the kinetic energy of the airplane in landing, the nose-high-attitude technique must, of course, be used if sufficient runway length is available; otherwise, other means of arresting the airplane must be provided.

Effect of Flap Retraction

The effect of instantaneous flap retraction on the ground-run distance during braking is shown in figure 14 for a touchdown speed of 5 percent above stalling speed with zero residual thrust and $\mu_b = \mu_a$. For the swept-wing transport, reductions in ground-run distance are

obtained through instantaneous flap retraction at values of μ_a down to 0.05 (fig. 14(e)). The reductions at the higher values of μ_a are appreciable. With gradual flap retraction the reduction would be smaller and would depend on the flap retraction time. For the other airplanes instantaneous flap retraction produces little or no reduction in ground-run distance above values of μ_a of about 0.2 $\left(\text{or } 0.4 \text{ for } \mu_b = 0.5\mu_a\right)$ and a relatively large increase below these values. At the higher touch-down speeds, 20 percent above stalling speed for the swept-wing transport and 30 percent for the unswept-wing and swept-wing fighters (fig. 15), the value of μ_a above which the reduction (or below which an increase) in ground-run distance is obtained is about the same as at the lower touchdown speed, but the magnitude of the reduction (or increase) is considerably greater. With residual thrust of 0.025W (fig. 16), instantaneous flap retraction increases the ground-run distance appreciably above that with zero residual thrust at the low values of μ_a. At the higher values of μ_a the residual thrust of 0.025W has a negligible effect on the decrease in ground-run distance obtained with flap retraction.

CONCLUDING REMARKS

Calculations of ground-run distance for several different types of jet airplanes having braking coefficients equal to the maximum available tire-to-ground friction coefficient indicated that no reduction in ground-run distance could be effected by maintaining a nose-high attitude during the ground run for a swept-wing transport, an unswept-wing fighter, and one type of swept-wing fighter. Some small reductions in ground-run distance were indicated for two other swept-wing fighters on a very slippery runway (at values of maximum available tire-to-ground friction coefficient less than about 0.10). A nose-high-attitude angle in the neighborhood of the stall angle of attack during a ground run of a delta-wing fighter resulted in an appreciable reduction in landing distance at values of maximum available tire-to-ground friction coefficient less than about 0.2 (or about 0.4 for braking coefficients equal to 50 percent of the maximum available tire-to-ground friction coefficient). If, however, the nose-high-attitude angle were limited by tail-pipe clearance or by other factors to about half the stall angle, no reduction in ground run would be indicated for the delta-wing fighter. Retracting the flaps at the instant of ground contact led to reductions in ground-run distance for the swept-wing transport for tire-to-ground friction coefficients down to about 0.05. For the unswept- and swept-wing fighters, flap retraction resulted in an appreciable increase in ground-run distance at maximum available tire-to-ground friction coefficients less than about 0.2

(or less than about 0.4 for braking coefficients equal to 50 percent of the maximum available tire-to-ground friction coefficient).

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 22, 1957.

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2. Wetmore, J. W.: The Rolling Friction of Several Airplane Wheels and Tires and the Effect of Rolling Friction on Take-Off. NACA Rep. No. 583, 1937.

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TABLE I.- AIRPLANE PHYSICAL CHARACTERISTICS

Airplane	W/S, lb/sq ft	Aspect ratio	Sweepback of wing quarter chord, deg	α_g, deg	i_w, deg
Unswept-wing fighter	54	5.9	0	0	0
Swept-wing transport	70	9.4	35	3	0
Swept-wing fighter A	50	4.8	35	0	0
Swept-wing fighter B	48	3.0	45	0	0
Swept-wing fighter C	52	4.5	35	0	0
Delta-wing fighter	28	2.0	52	0	0

TABLE II.- FLAP CHARACTERISTICS AT ANGLE

OF ATTACK FOR THREE-POINT ATTITUDE

Airplane	$\Delta C_{L,f}$	$\Delta C_{D,f}$
Unswept-wing fighter	0.78	0.132
Swept-wing transport	.87	.044
Swept-wing fighter A	.40	.060
Swept-wing fighter B	.31	.084
Swept-wing fighter C	.39	.098

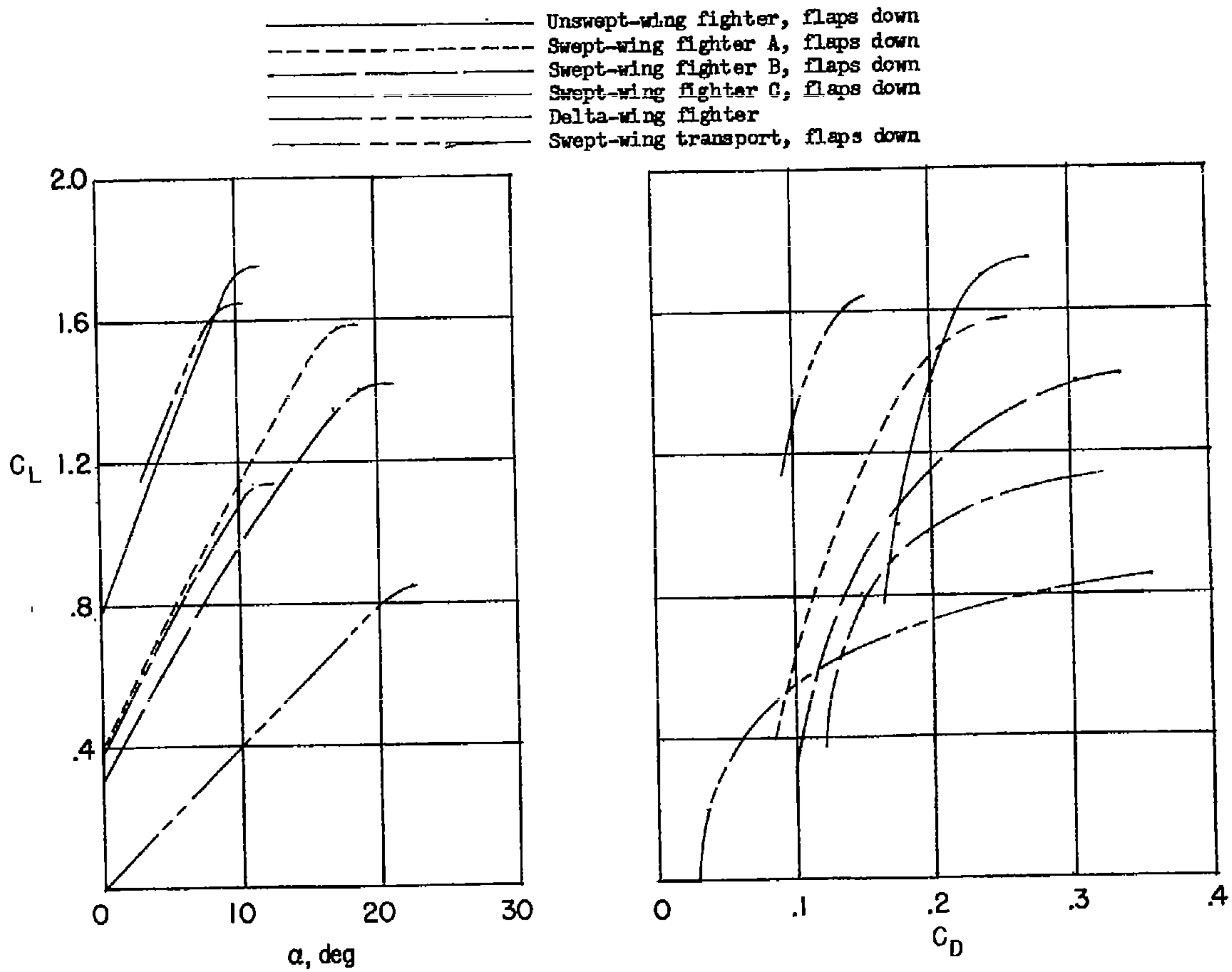


Figure 1.- Aerodynamic characteristics with ground effect included.

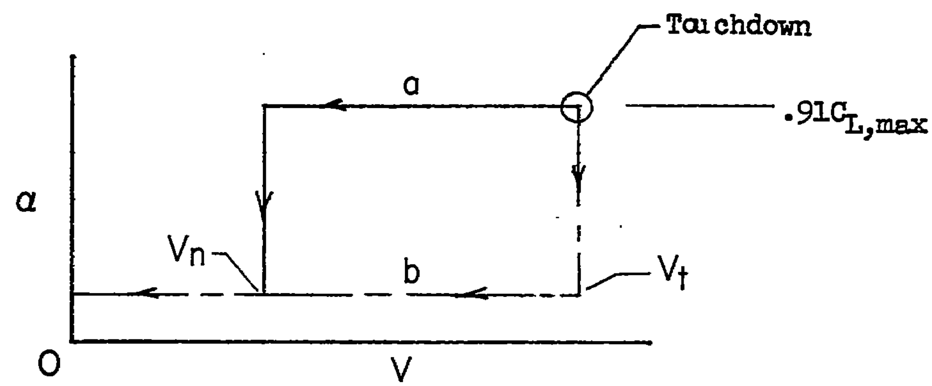


Figure 2.- Assumed variation of angle of attack with speed during landing ground run. $V_t = 1.05V_s$.

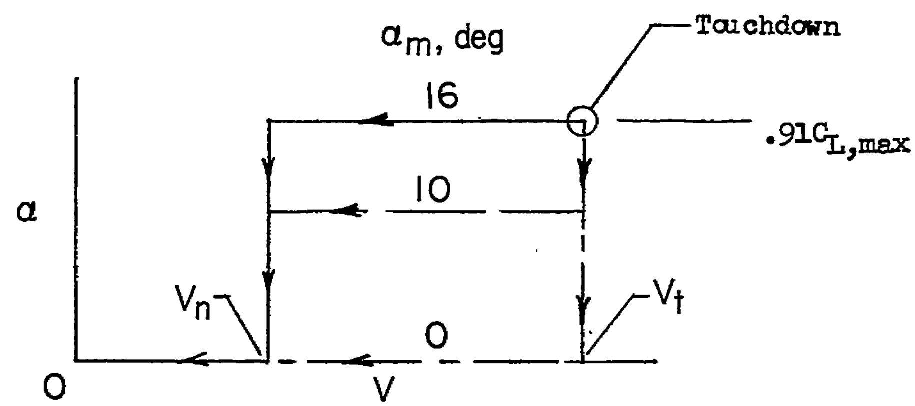


Figure 3.- Assumed variation of angle of attack with speed during landing ground run for swept-wing fighter B. $V_t = 1.05V_s$.

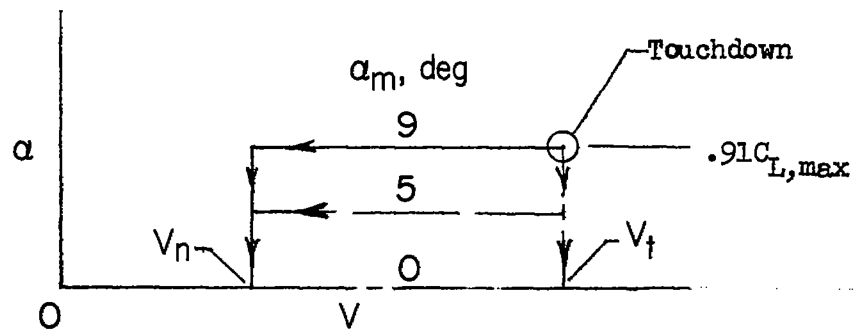


Figure 4.- Assumed variation of angle of attack with speed during landing ground run for swept-wing fighter C. $V_t = 1.05V_s$.

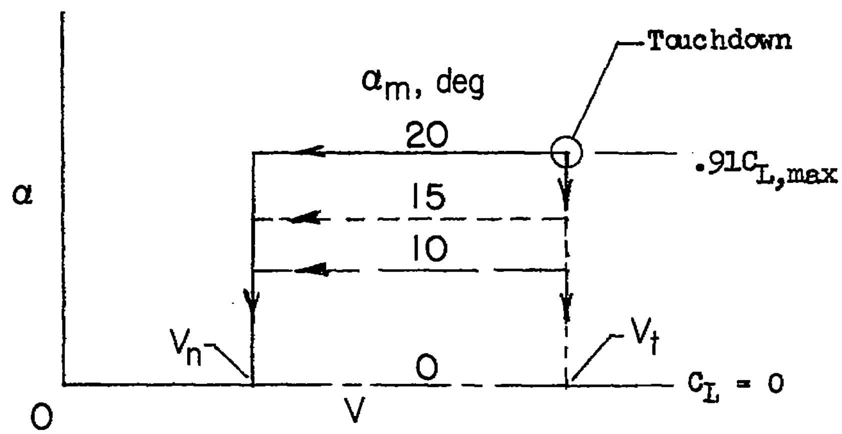


Figure 5.- Assumed variation of angle of attack with speed during landing ground run for delta-wing fighter. $V_t = 1.05V_s$.

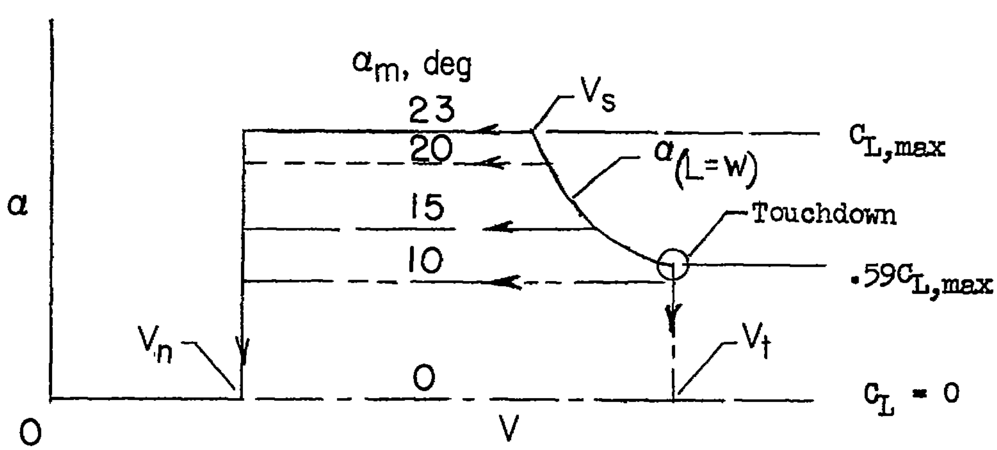
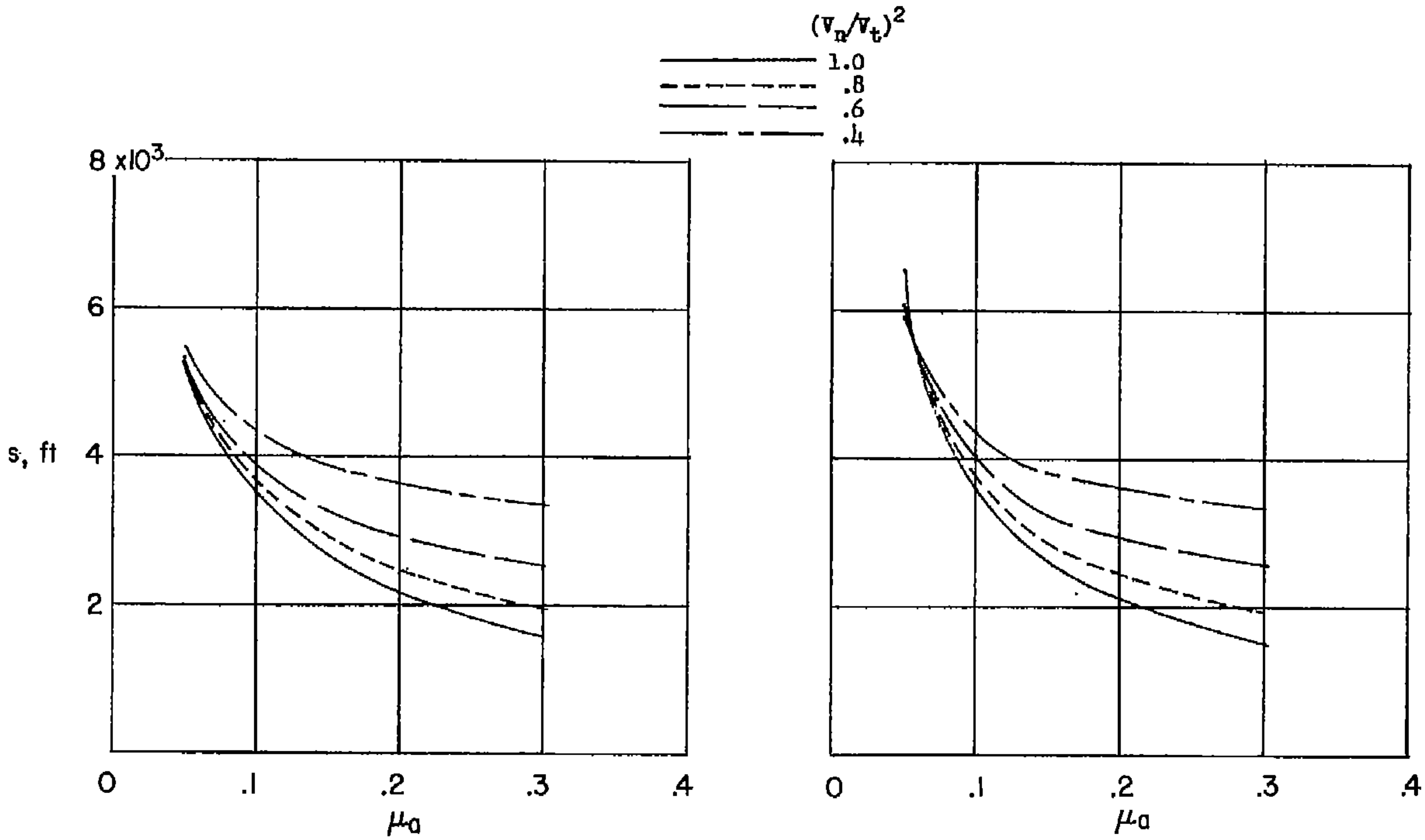


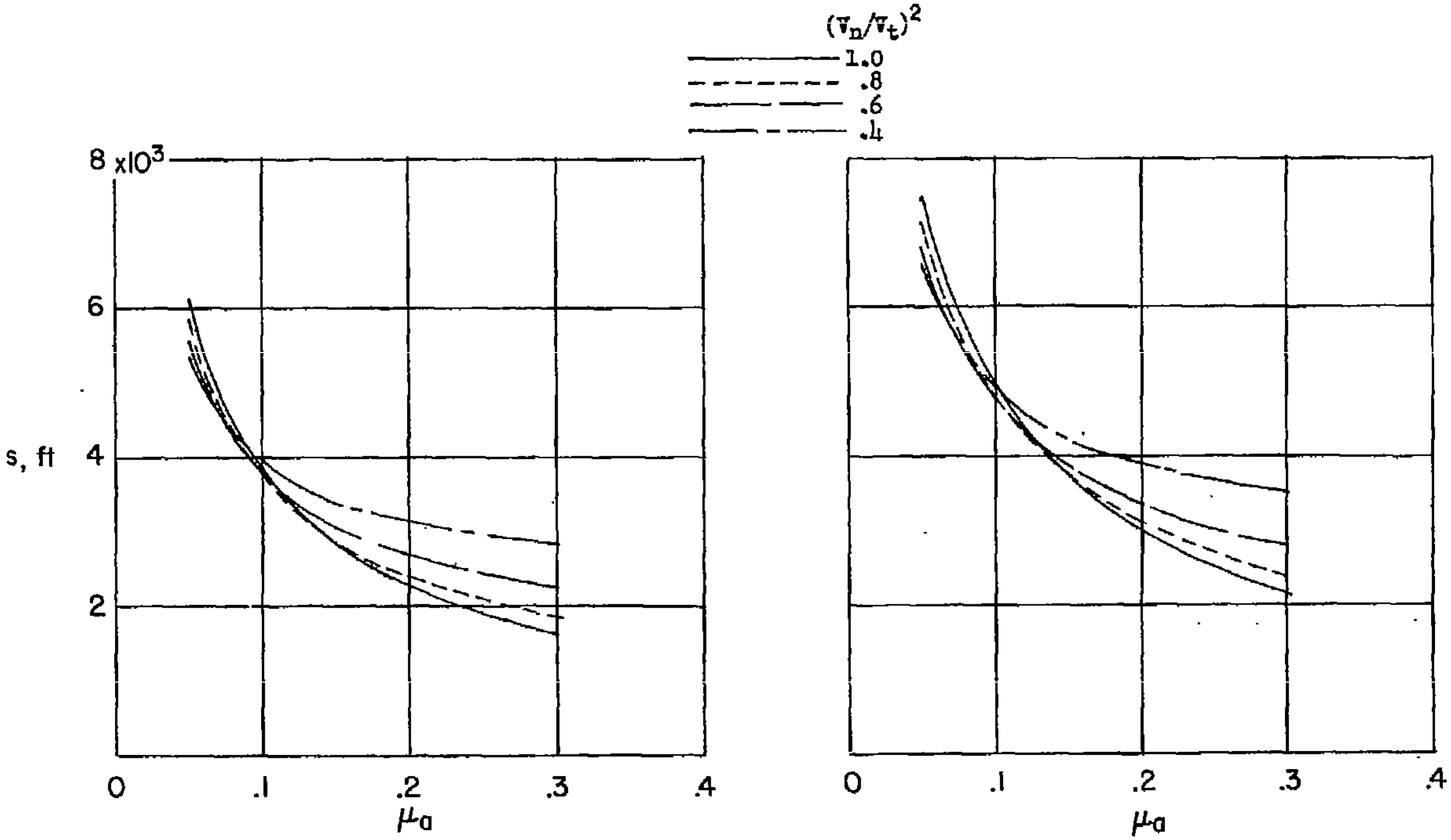
Figure 6.- Assumed variation of angle of attack with speed during landing ground run for delta-wing fighter. $V_t = 1.30V_s$.



(a) Unswept-wing fighter. $\alpha_m = 9^\circ$.

(b) Swept-wing fighter A. $\alpha_m = 14^\circ$.

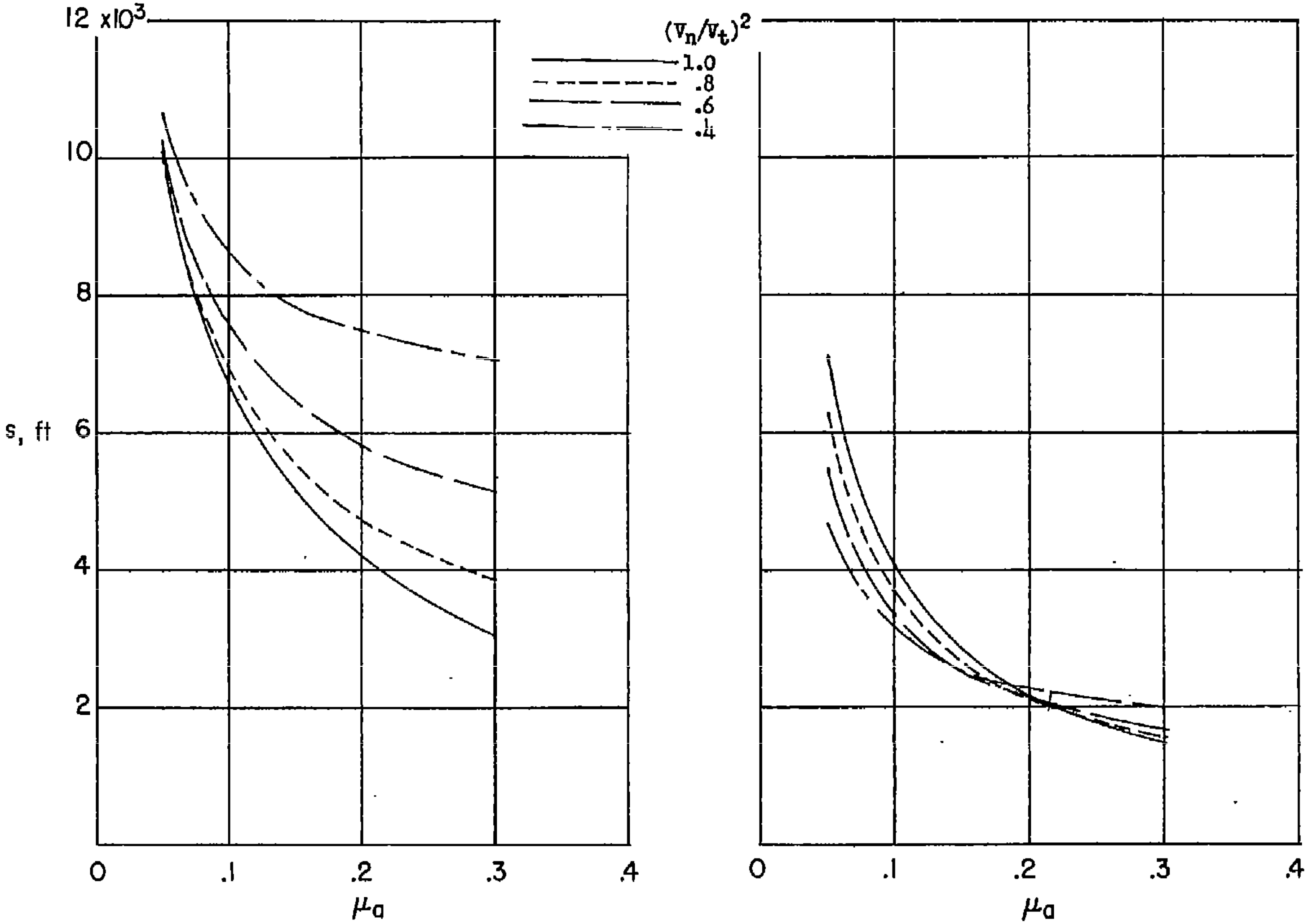
Figure 7.- Ground-run distance for several airplanes and various values of $\left(V_n/V_t\right)^2$. $V_t = 1.05V_s$; $T = 0$; $\mu_b = \mu_a$.



(c) Swept-wing fighter B. $\alpha_m = 16^{\circ}$.

(d) Swept-wing fighter C. $\alpha_m = 9^{\circ}$.

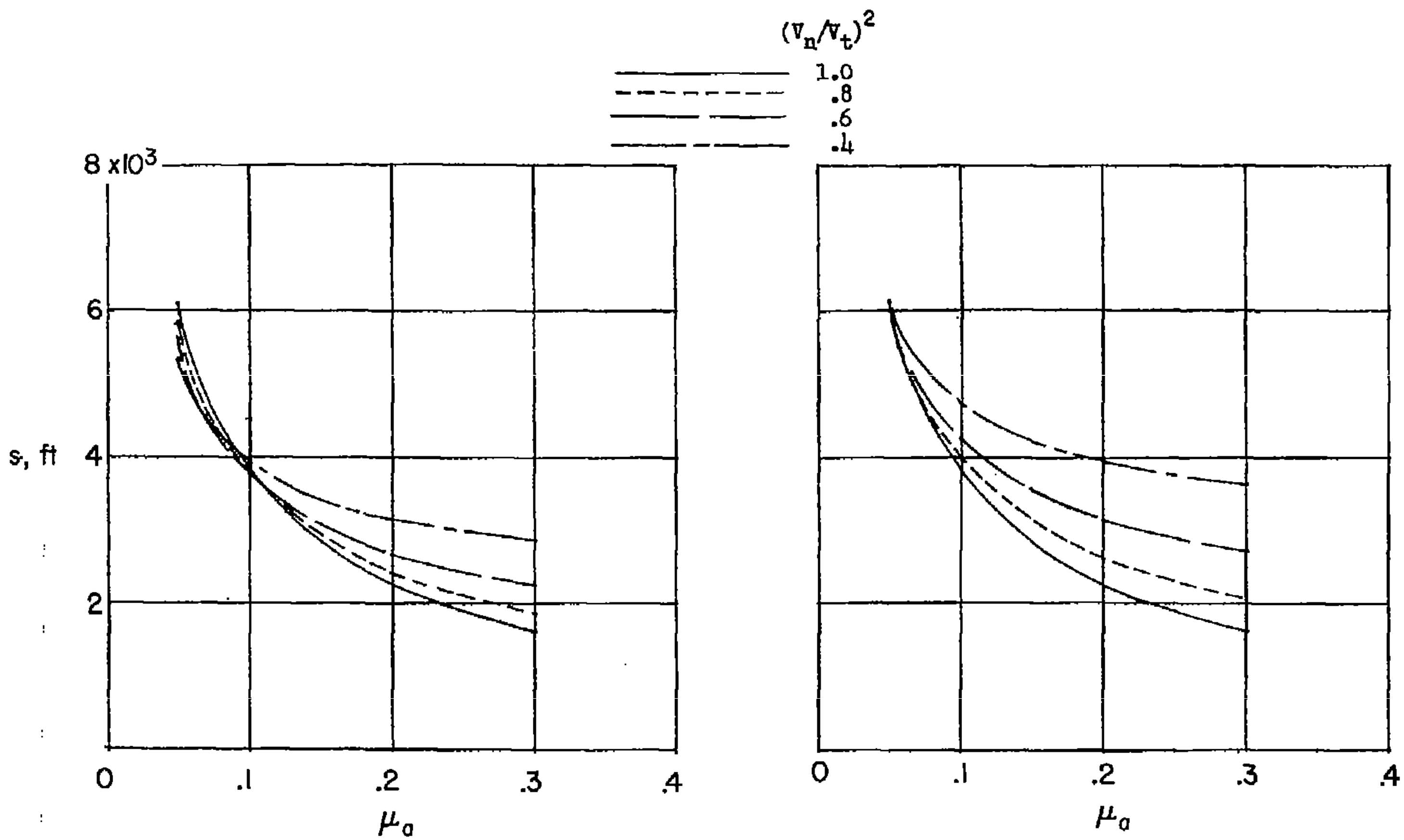
Figure 7.- Continued.



(e) Swept-wing transport. $\alpha_m = 7^\circ$.

(f) Delta-wing fighter. $\alpha_m = 20^\circ$.

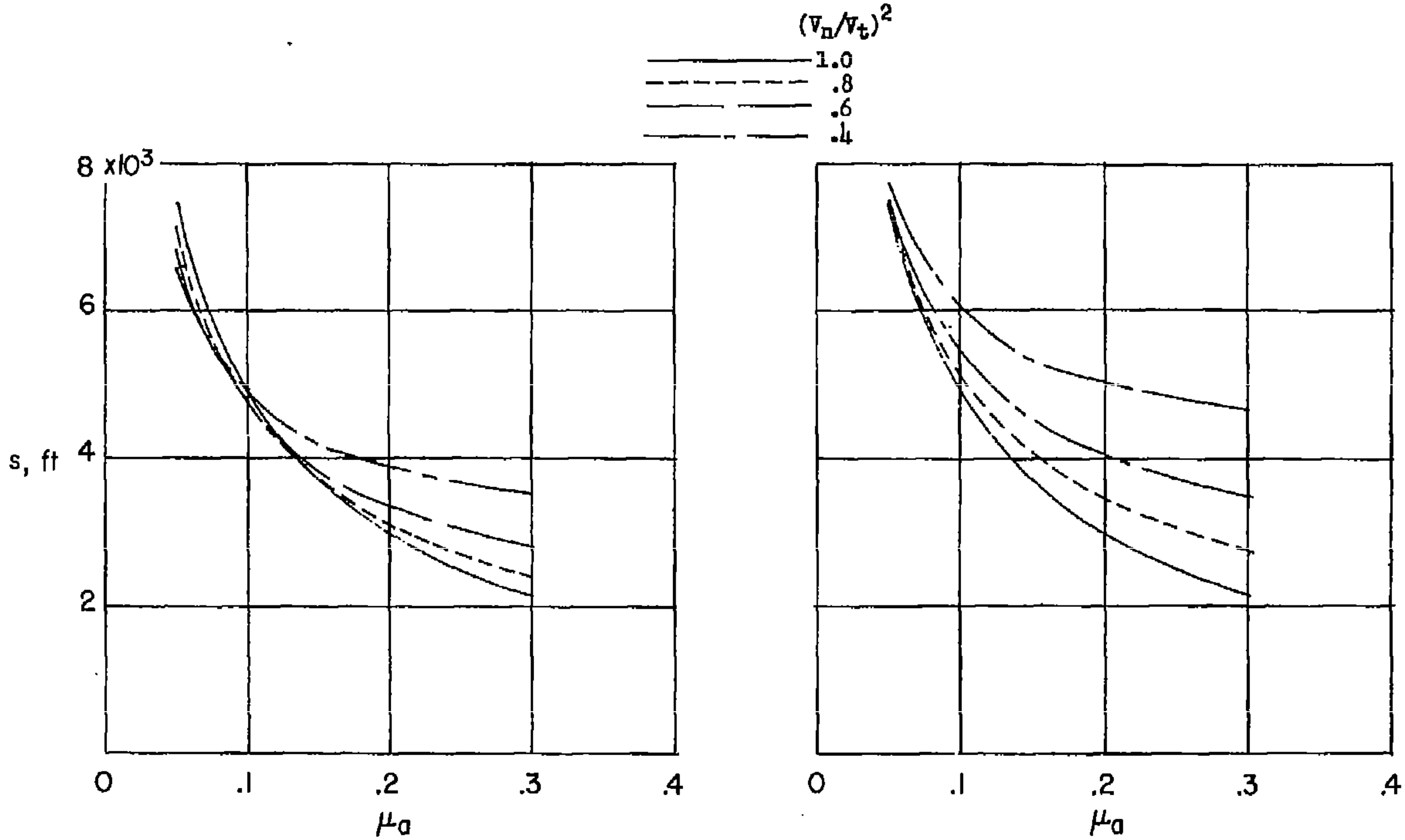
Figure 7.- Concluded.



(a) $\alpha_m = 16^\circ$.

(b) $\alpha_m = 10^\circ$.

Figure 8.- Ground-run distance for swept-wing fighter B for two values of the attitude angle α_m. $V_t = 1.05V_s$; $T = 0$; $\mu_b = \mu_a$.



(a) $\alpha_m = 9^\circ$.

(b) $\alpha_m = 5^\circ$.

Figure 9.- Ground-run distance for swept-wing fighter C for two values of the attitude angle α_m. $V_t = 1.05V_s$; $T = 0$; $\mu_b = \mu_a$.

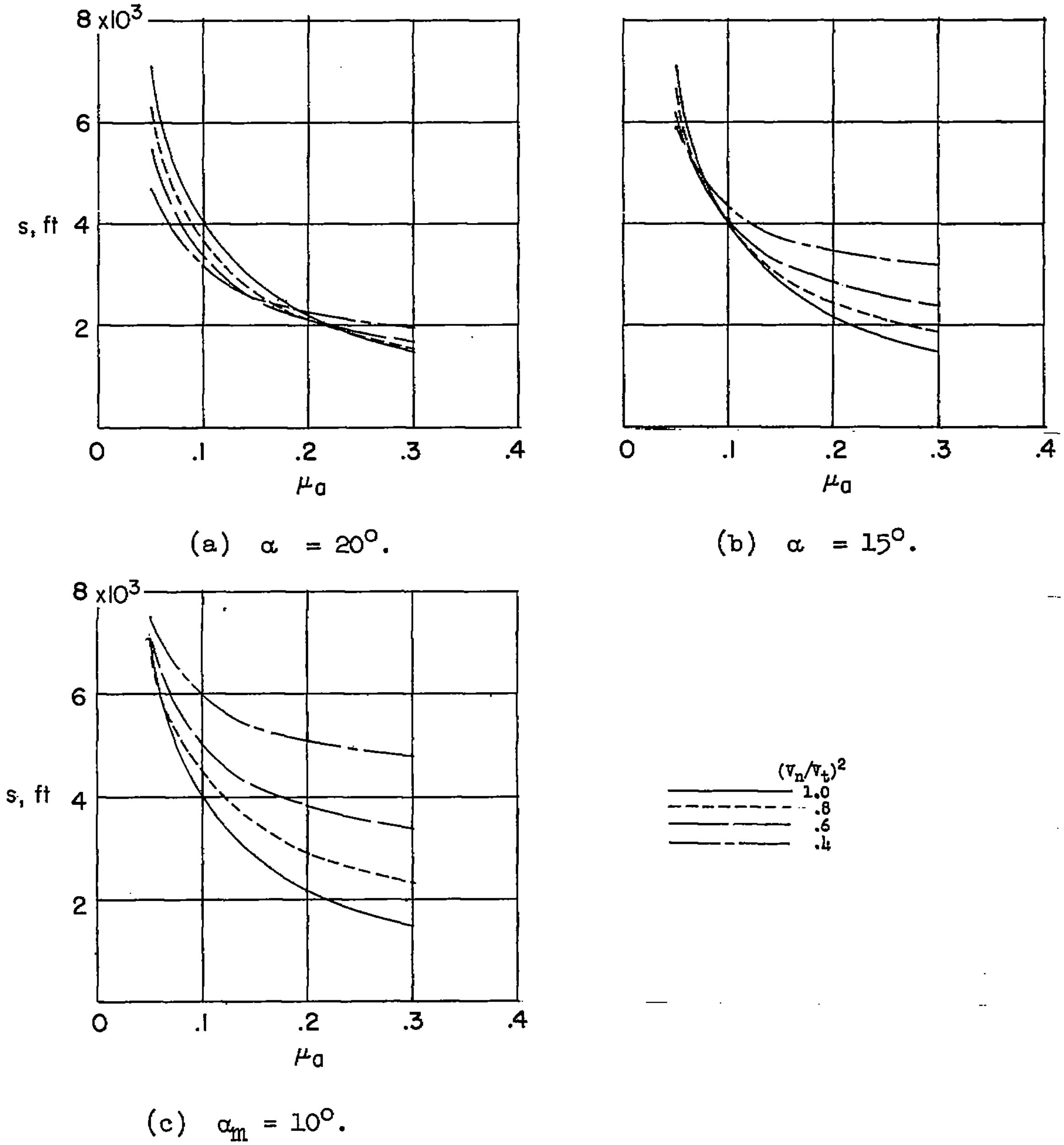
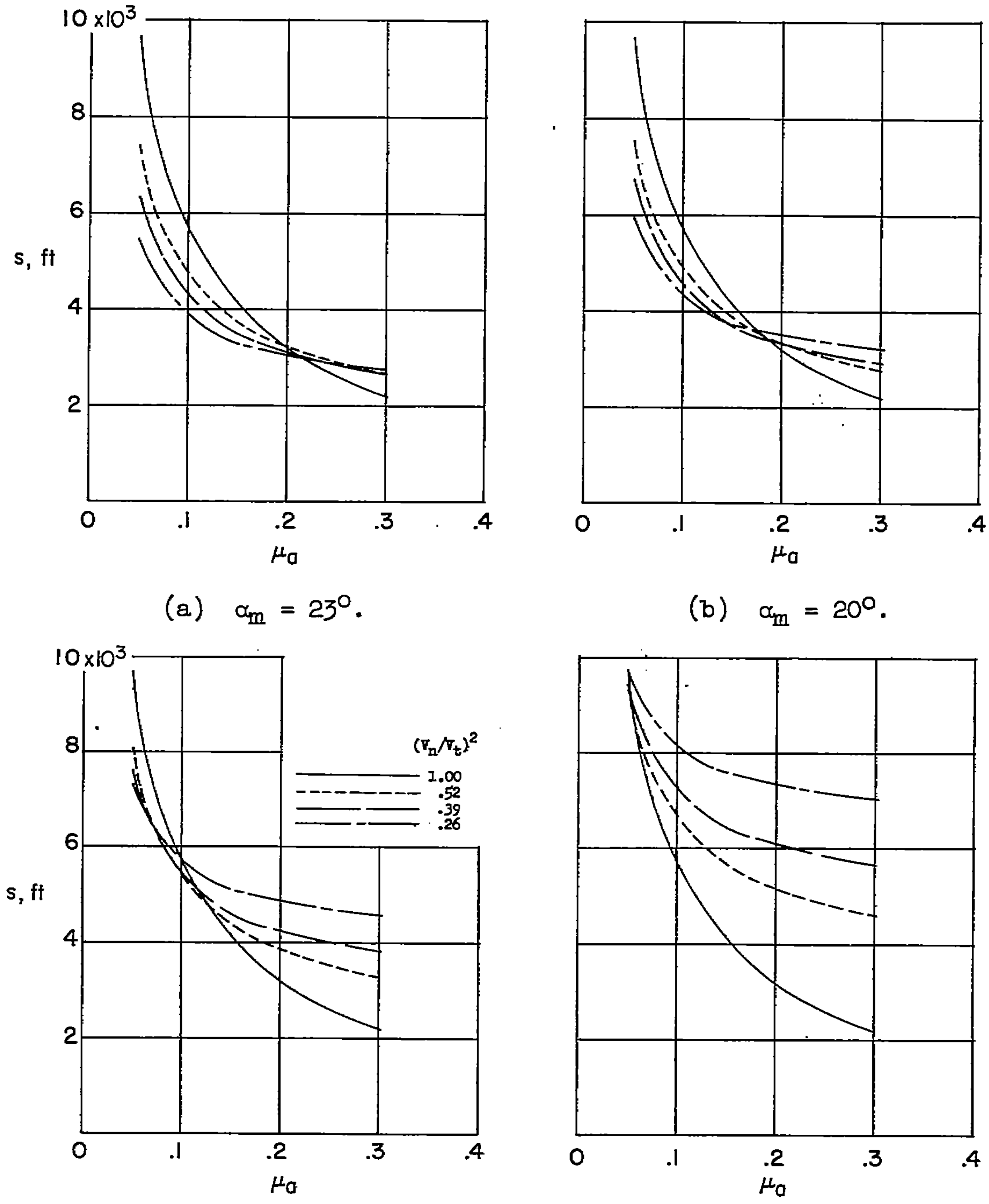


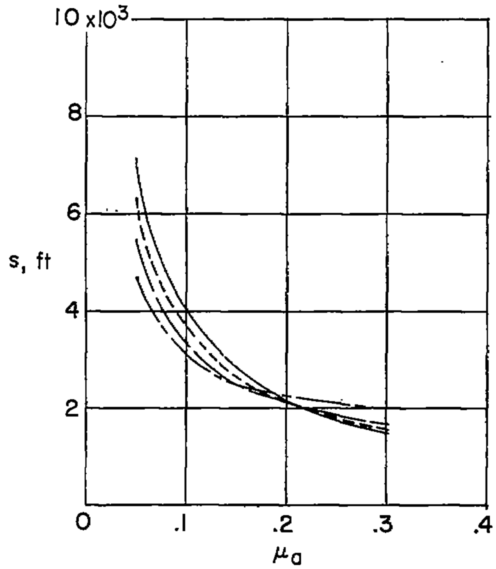
Figure 10.- Ground-run distance for delta-wing fighter for several values of attitude angle α_m. $V_t = 1.05V_s$; $T = 0$; $\mu_b = \mu_a$.



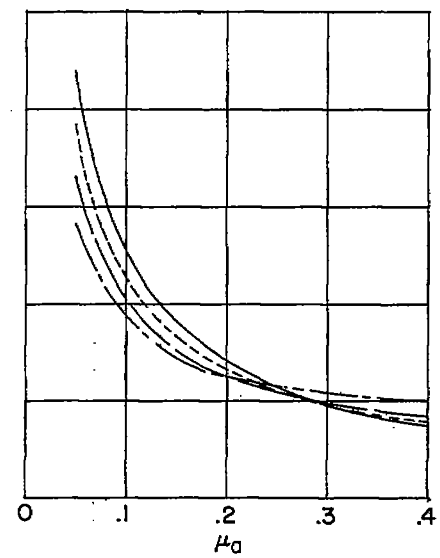
(c) $\alpha_m = 15^\circ$.

(d) $\alpha_m = 10^\circ$.

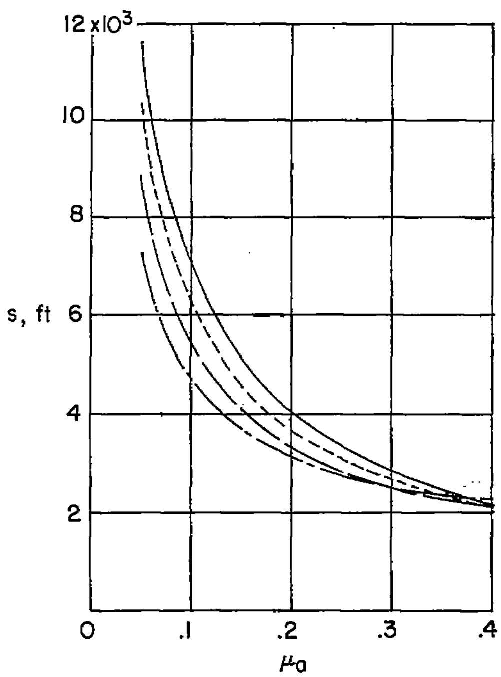
Figure 11.- Ground-run distance for delta-wing fighter for several values of attitude angle α_m. $V_t = 1.30V_s$; $T = 0$; $\mu_b = \mu_a$.

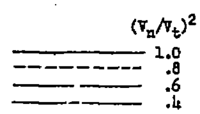


(a) $\mu_b = \mu_a$.



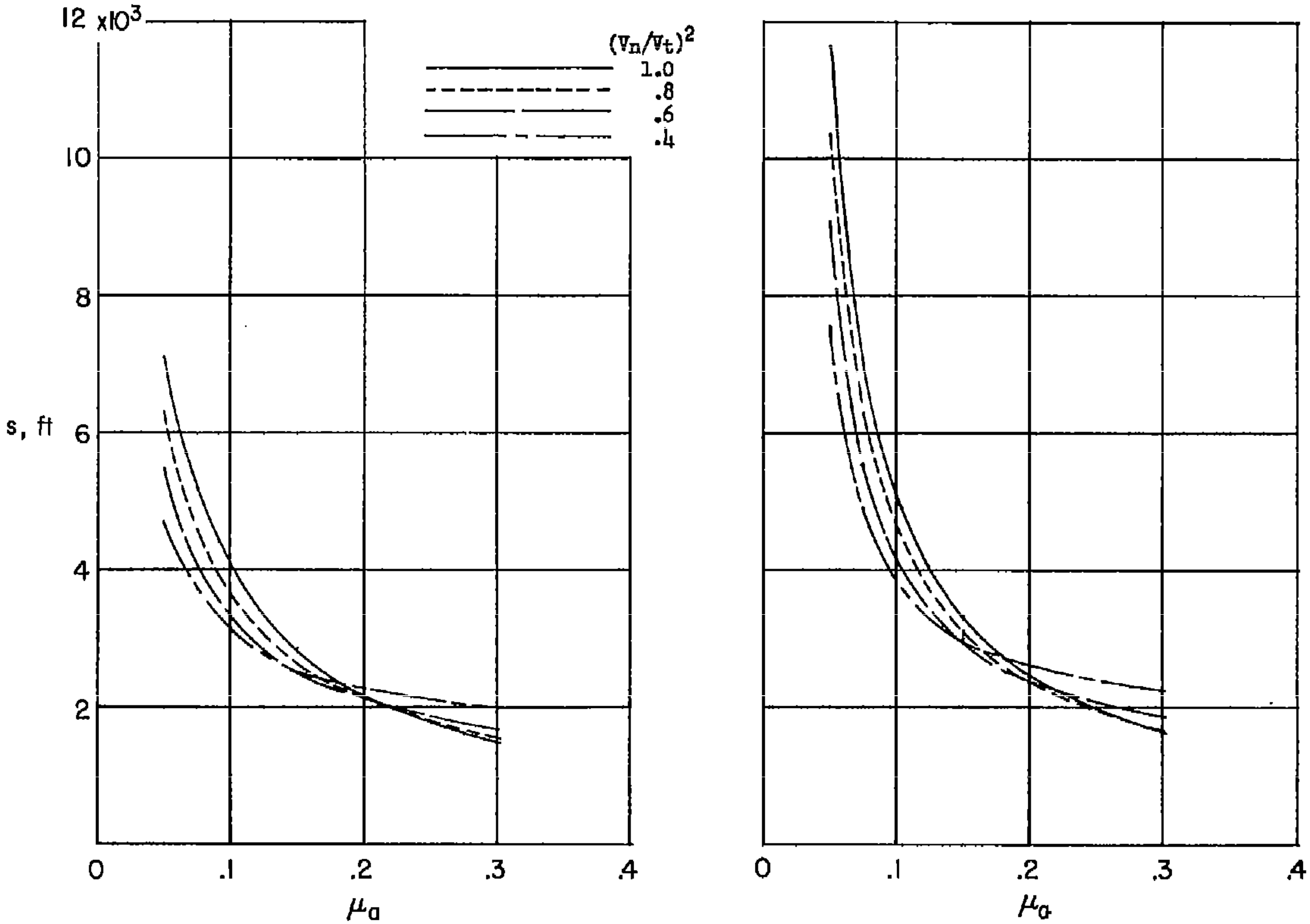
(b) $\mu_b = 0.75\mu_a$.





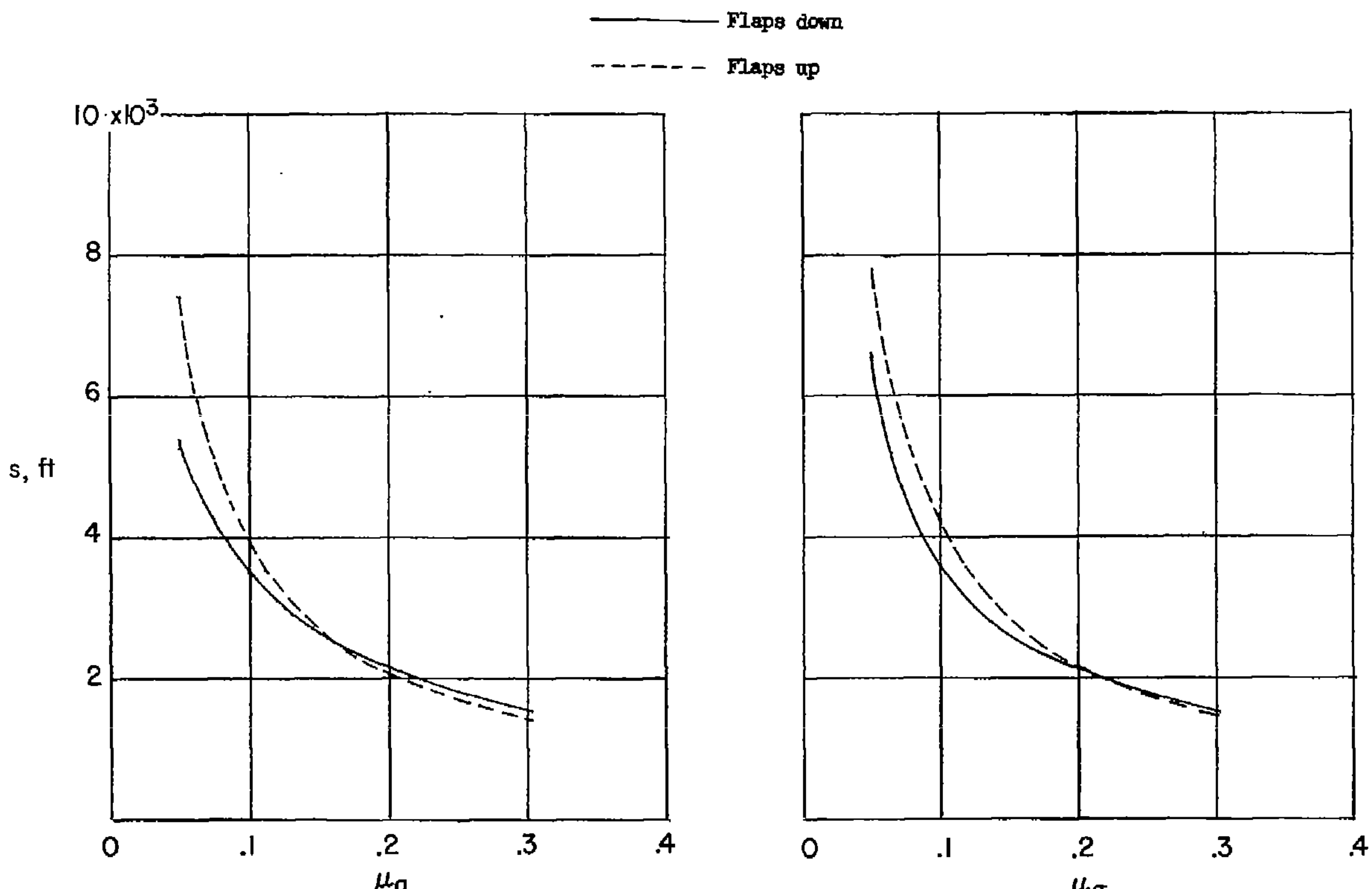
(c) $\mu = 0.50\mu_a$.

Figure 12.- Ground-run distance for delta-wing fighter for several values of brake effectiveness. $V_t = 1.05V_s$; $\alpha_m = 20^\circ$.



(a) T = 0. (b) T = 0.025W.

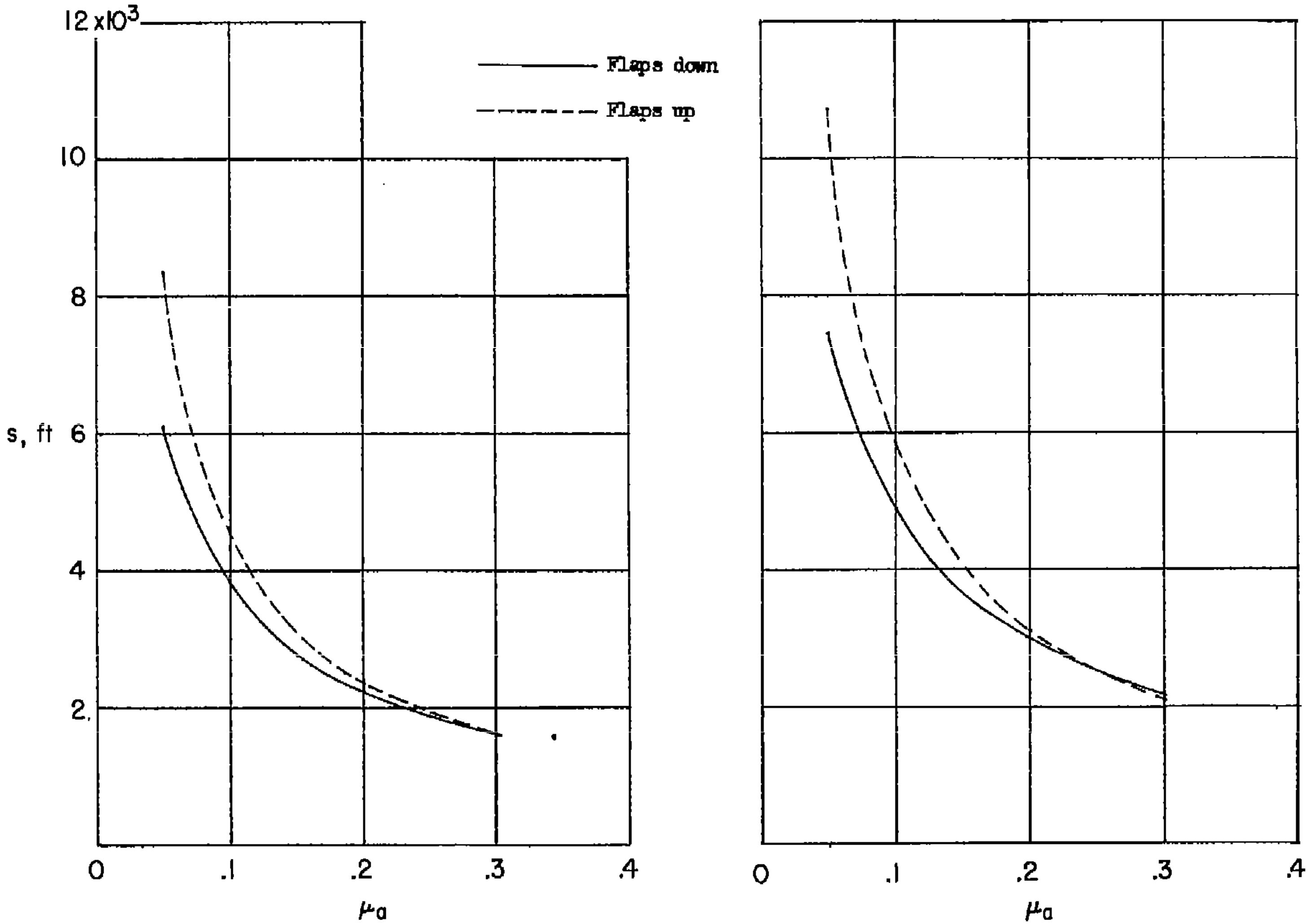
Figure 13.- Effect of residual thrust on ground-run distance for delta-wing fighter. $V_t = 1.05V_s$; $\mu_b = \mu_a$; $\alpha_m = 20^\circ$.



(a) Unswept-wing fighter.

(b) Swept-wing fighter A.

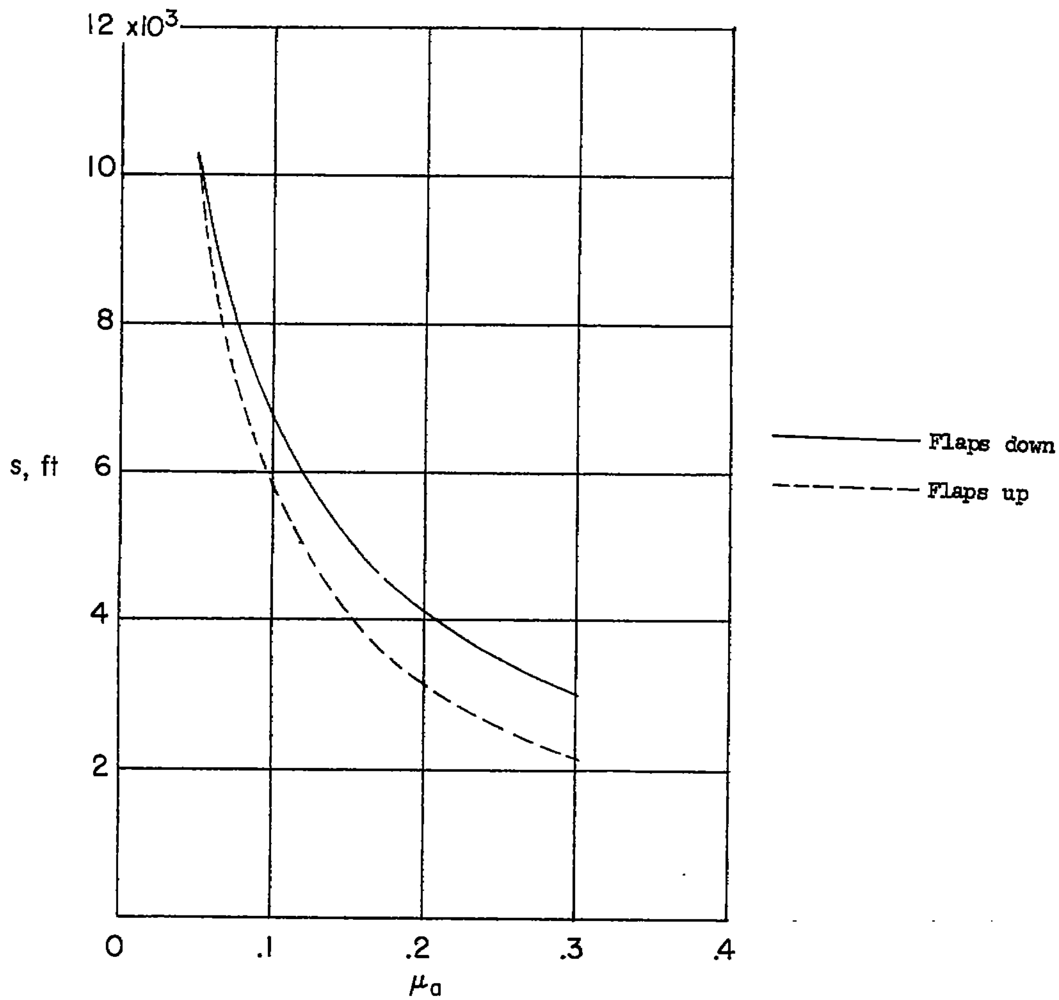
Figure 14.- Effect of flaps on ground-run distance for several airplanes. $V_t = 1.05V_s$; $T = 0$; $\mu_b = \mu_a$.



(c) Swept-wing fighter B.

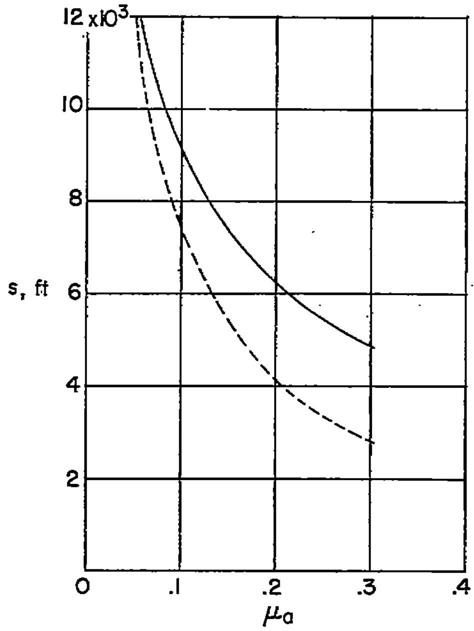
(d) Swept-wing fighter C.

Figure 14.- Continued.

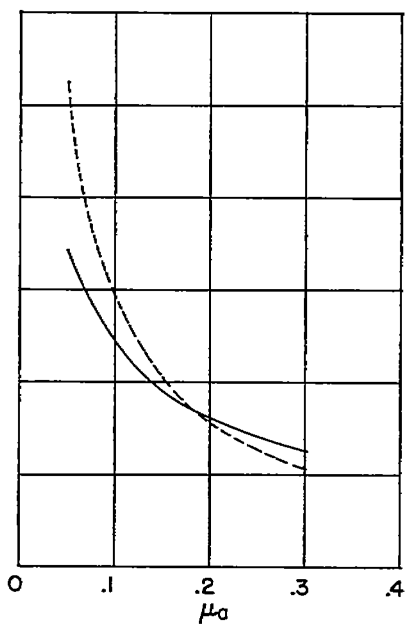


(e) Swept-wing transport.

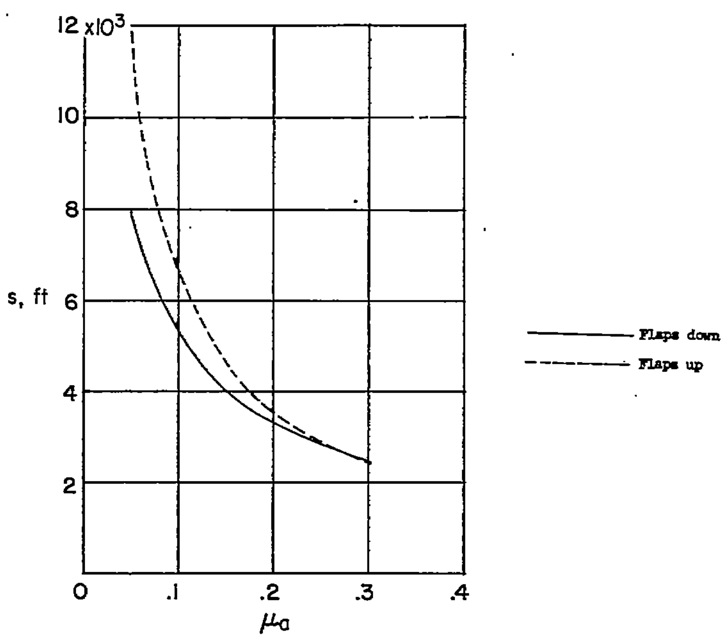
Figure 14.- Concluded.



(a) Swept-wing transport. $V_t = 1.2V_s$.

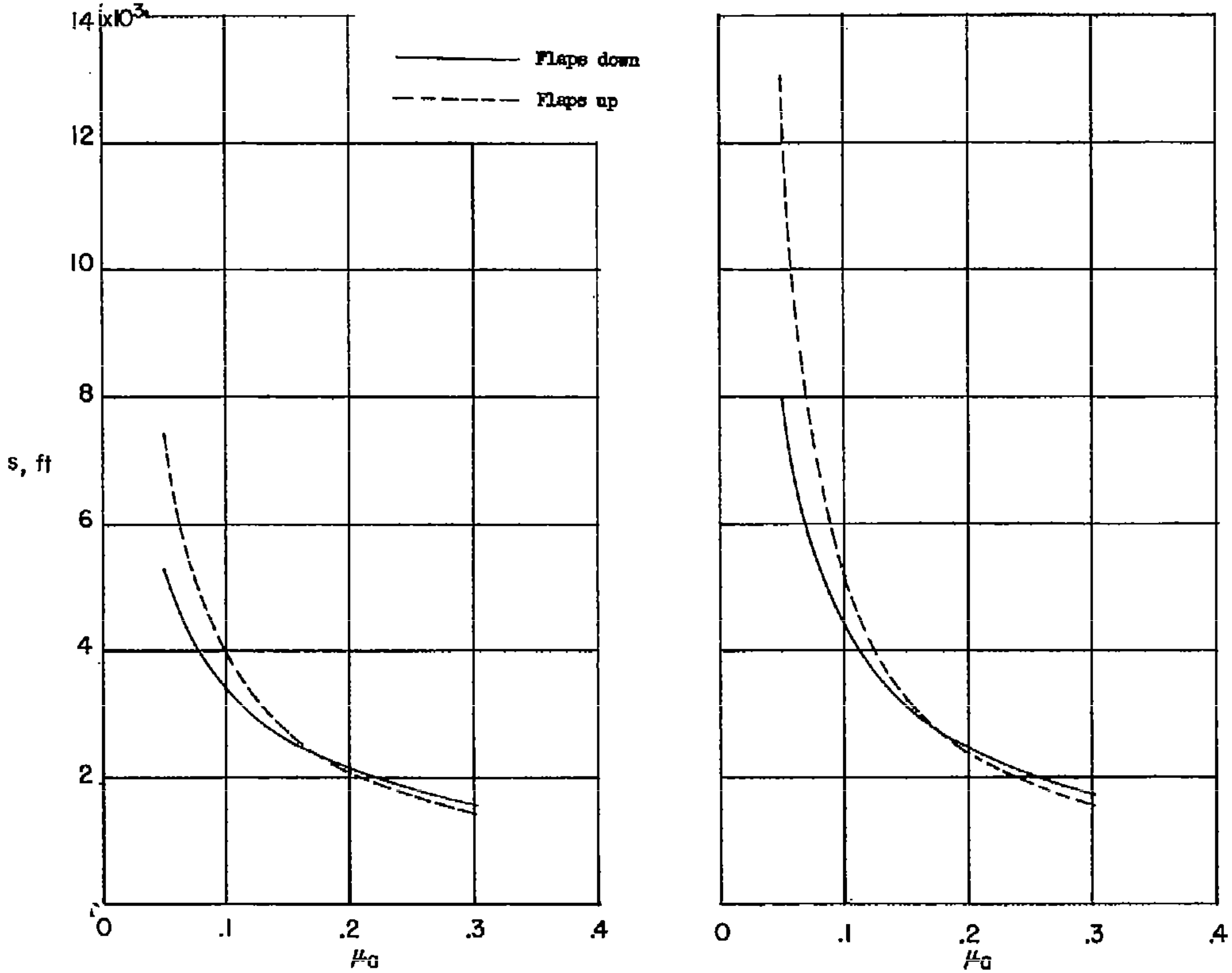


(b) Unswept-wing fighter. $V_t = 1.3V_s$.



(c) Swept-wing fighter B. $V_t = 1.3V_s$.

Figure 15.- Effect of flaps on ground-run distance. $T = 0$; $\mu_b = \mu_a$.



(a) T = 0.

(b) T = 0.025W.

Figure 16.- Effect of flaps and residual thrust on ground-run distance for the straight-wing fighter. $V_t = 1.05V_s$; $\mu_b = \mu_a$.